

HIGH BORON CONTENT IN IRRIGATIONW WATER

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INTRODUCTION

Boron is an essential element for the growth of plants. Optimum yields of some plants are obtained at concentrations of a few tenths mg/L in nutrient solution. However, at concentrations of 1.0 mg/L, boron is toxic to a number of sensitive plants. Eaton (1935, 1944) conducted an extensive investigation based on sand culture studies to determine tolerance of boron for a large number of plants. In general, sensitive crops (citrus, fruit trees) showed toxicities when irrigated with water having a boron content at 1 mg/L or less, semitolerant crops (wheat, oat, barley, potato) at 1 to 2 mg/L, and tolerant crops (sugar beet, alfalfa, carrot, cabbage) at 2 to 4 mg/L. At concentrations above 4 mg/L, the irrigation water was generally unsatisfactory for most crops.

The majority of surface waters used for irrigation in Saskatchewan have a low boron content. A survey (Nicholaichuk et al. 1983) indicates that except for the Coronach project, all other surface water supplies used for irrigation in Saskatchewan contained less than 1.0 mg/L of boron. At Coronach, the water used for irrigation contained an average boron content of 1.7 mg/L. Thus, it appears that in Saskatchewan boron toxicity induced by irrigation water is not presently a problem.

Recently concern was expressed about possible boron toxicity that might be caused by the operation of the Coronach thermal power plant in southern Saskatchewan. It is feared that if the water from the ash lagoons and heat exchanger reservoirs of the plant are discharged into the Poplar River it may lead to undesirable boron levels in the irrigation water downstream in the U.S.A.

The International Poplar River Water Quality Board and Committees of the International Joint Commission, in assessing the Saskatchewan controversy, had difficulty in establishing what should be regarded as an acceptable boron content in irrigation water. They concluded that the scientific literature was inadequate in this respect (International Poplar River Water Quality Board of International Joint Commission 1979).

Interest in boron toxicity has now also extended to concern over the use of groundwater, sewage effluent and impounded surface water where the boron contents are generally much higher than that of the surface water. As a result, Saskatchewan Environment requested Agriculture Canada to set up studies to collect information on crop production under stress conditions induced by boron in irrigation water and to develop some criteria for future application.

In response to the request, four of us at the Swift Current Research Station were asked to conduct a detailed review and assessment of the need for further boron toxicity research, especially in relation to boron in irrigation water. In this paper, we discuss confusion which apparently exists in the literature with regard to boron criteria for evaluating irrigation water quality. Weaknesses in the currently used criteria tables are identified and suggestions are made to rectify these weaknesses.

CONFUSION IN BORON TOXICITY CRITERIA

Ultimately, all current plant boron toxicity criteria used for evaluating irrigation waters high in boron are based on Eaton's sand culture studies reported in 1935 and 1944 (Scofield 1936; U.S. Salinity Laboratory Staff 1954; Wilcox 1960; Allison 1964; Bingham 1973; Bernstein 1974; Shainberg and Oster 1979). One of the criteria was proposed by Wilcox (1960) and adopted by Ayers and Westcot (1976) (Table 1).

Table 1. Relative tolerance of crops and ornamentals to a B[†]
(Tolerance decreases in descending order in each column)
(From Ayers and Westcot 1976)

Tolerant (4.0 mg/L of B)	Semitolerant (2.0 mg/L of B)	Sensitive (1.0 mg/L of B)
--	Sunflower, native	--
Asparagus	Potato	Walnut
Palm	Cotton	--
--	Tomato	Jersalem artichoke
Sugarbeet	--	Navy bean
Mangel	Radish	--
Garden beet	Field pea	Plum
Alfalfa	--	Pear
--	Olive	Apple
Broadbean	Barley	Grape
Onion	Wheat	--
Turnip	Corn	Persimmon
Cabbage	Milo	Cherry
Lettuce	Oat	Peach
Carrot	--	Apricot
--	Bell pepper	Orange
--	Sweet potato	Avocado
--	Lima bean	Grapefruit
--	--	Lemon
2.0 mg/L of B	1.0 mg/L of B	0.3 mg/L of B

[†] Relative tolerance is based on B in irrigation water at which B toxicity symptoms were observed when plants were grown in sand culture. Does not necessarily indicate a reduction in yield.

Apparently, there is some confusion with regard to the "concentration" cited in the literature. The same boron tolerance table (i.e., Table 1) has appeared in many reports, but the concentrations of boron were often interpreted differently. Ayers and Westcot (1976) indicated that the concentrations presented were based on the levels of boron in the irrigation water at which toxicity symptoms were observed in plants grown in sand culture. Allison (1964) simply noted that the concentrations were the limits of tolerance for boron in irrigation water. Bernstein (1974) interpreted the concentrations as being the limiting boron levels in the soil saturation extracts.

When boron is added to soils by means of irrigation, part of the boron will remain in soil solution and part is adsorbed ("fixed") by soil particulates. An equilibrium presumably exists between the solution and adsorbed boron (Eaton and Wilcox 1939; Russell 1973; Bingham 1973). It has been reported that plants respond primarily to the soil solution boron, independently of the amount of boron that is adsorbed by soil (Hatcher et al. 1959; Ryan et al. 1977). Thus, any attempts to assess plant boron toxicity should be given in terms of the soil solution boron. As a matter of fact, in the field, the concentrations of the soil solution, the irrigation water, and the saturation extract are not the same. They should not be used interchangeably. Only in sand culture experiments where, due to excessive leaching, it would be expected that the soil solution concentrations were identical with irrigation water concentrations. Thus, it is important to know the eventual boron concentration of the soil solution resulting from the concentration of irrigation water under differing management practices. Until then, it seems appropriate to use boron concentration established by Eaton.

RELATIONSHIP BETWEEN IRRIGATION WATER BORON AND SOIL SOLUTION BORON

Few irrigation waters have enough boron to injure plants directly. It is the concentration of boron in the soil due to continued use and evapotranspiration that leads to the eventual toxicity problems (Eaton 1935).

When the plant uptake of boron is small compared to the amounts applied in the water, the boron concentration in the soil solution will increase with time. Eventually, however, an equilibrium will be reached when the amount of boron added to the root zone by irrigation is equal to the amount removed from the root zone by the crop and by leaching. Thus, to prevent the continuous buildup of boron in the root zone, it is essential that more water be applied than the plant requires so that the excess water will drain below the root zone. This fraction of the applied water is referred to as the leaching fraction (LF). For efficient and continued crop production, the LF must be high enough to prevent the buildup of boron in the root zone to a toxic level; but it must be low enough to prevent excessive waste of water.

Prior to reaching the equilibrium condition, the boron levels that the plants are exposed to will be less than the equilibrium levels.

Thus, for a long-term irrigation project, it is the equilibrium condition that will be of most concern.

The boron concentration of the soil solution at equilibrium can be calculated based on the mass balance equation, taking into account water and boron uptake patterns by the plant from the soil (Jame et al. 1982). At equilibrium boron concentration of the soil solution will generally increase gradually from a level near the soil surface, equivalent to that of the irrigation water, to a level near the bottom of the root zone where the boron concentration is determined primarily by the degree of leaching. When high LF's are applied, the boron concentration of the soil solution will be uniform and will change relatively little with depth. In contrast, if the LF is low the resultant boron concentration will vary considerably. Boron concentrations near the soil surface will be close to those of the irrigation water and those near the bottom of the root zone will be much higher.

Jame et al. (1982) estimated that for irrigation water concentration between 0.5 and 10 mg/L, the resulting boron concentration (weighted average based on 40-30-20-10% root distribution in each soil segment) would be about 1.9 to 2.7 times the boron concentration in the irrigation water at a LF of 0.1. It would about 1.4 to 1.9 times for a LF of 0.25; and about 1.3 to 1.5 times for a LF of 0.4 (Table 2).

Table 2. Calculated equilibrium boron concentrations of the soil solution in alfalfa fields irrigated with water of vary boron concentrations (From Jame et al. 1982)

Boron concentration of irrigation water (mg/L)												
0.5				1.0			5.0			10.0		
Leaching fraction (LF)												
Depth (cm)	0.1	0.25	0.4	0.1	0.25	0.4	0.1	0.25	0.4	0.1	0.25	0.4
0	0.50	0.5	0.5	1.0	1.0	1.0	5.0	5.0	5.0	10.0	10.0	10.0
30	0.68	0.62	0.58	1.48	1.34	1.24	7.74	7.06	6.51	15.55	14.20	13.09
60	1.00	0.78	0.67	2.39	1.85	1.54	13.22	10.28	8.44	26.73	20.81	17.07
90	1.57	0.98	0.76	4.26	2.53	1.86	25.34	14.85	10.55	51.66	30.24	21.43
120	2.46	1.15	0.83	7.45	3.15	2.08	47.45	19.15	12.08	97.45	39.15	24.58
Wt												
avg†	0.95	0.72	0.63	2.33	1.67	1.40	13.19	9.23	7.58	26.75	18.67	15.30

† Weighted based on 40-30-20-10% root distribution pattern in each soil segment (top to bottom).

It seems clear to us that the concentrations cited in Eaton's reports are the concentrations of the culture solution he used to irrigate his crops, therefore, they should represent irrigation water concentration in his work. However, since the sand cultures used in his experiments were leached through every day with more than one pore volume of

water, it would be expected that in this condition the soil solution concentrations were identical to irrigation water concentrations. To transpose boron concentrations established by Eaton from his sand culture studies to the field, we believe that Eaton's values do not represent boron concentration in irrigation water but rather, should be interpreted as boron concentration in the soil solution.

In sand culture experiments plant roots are growing in a medium in which boron is uniformly distributed. In natural soil systems, the concentration of the soil solution in the profile is not uniform. Applying results obtained from sand culture to field conditions requires knowledge of the plant's response to boron in soil where the boron varies with depth. Bingham and Garber (1970) found that plant boron uptake was primarily influenced by the area of root surface that was exposed to a given boron concentration. Thus, it appears that the best way to relate the soil solution boron to the relative crop yield obtained from sand culture experiments is to use the average boron concentration weighted by the relative amount of root present in each depth segment within the root zone.

UNIVERSALLY APPLICABLE DATA

Even though the effect of boron toxicity for many crops has been appraised and reported in many publications, it appears that some confusion still exists in defining boron limits for plant growth. This is mainly because there is no universal method of assessing the boron toxicity level in soils. Procedures used for appraisal of boron levels in soil in relation to plant growth have differed from person to person. Although hot water soluble (HWSB) and saturation extract boron are being widely used as indicators, unfortunately, in most cases the results presented are very site specific and the parameters used are not easily translated into the most important parameters, that is, the boron concentration in the soil solution.

The lack of universality of the HWSB to predict plant response to boron in soil is because hot water extract boron from three major boron pools in soil, viz., an organic, an adsorbed inorganic, and a soluble inorganic pool. The relationship between HWSB and plant uptake is often only specific for a given soil texture and pH. To transpose the results obtained from HWSB, the interplay of the three boron pools and their relationship to boron uptake and to the HWSB needs to be defined. This is not an easy task.

Although the saturation extract boron has been regarded as comparable to soil solution boron (Bingham 1973), this is rarely true. When water is added to the soil to make the saturation paste, a portion of the adsorbed boron will go into solution; this amount will depend on the boron desorption characteristics of the soil. Since the boron concentration of the saturation extract does not take this boron adsorption/desorption characteristic of the soil into account, it does not provide a true representation of the soil solution boron.

can be used for irrigation. Rhoades (International Poplar River Water Quality Committee Main Report 1979), after reappraisal of Eaton's work, recommended that a value of 8.0 mg/L be used as the boron limit in soil solution for alfalfa.

Besides the lack of replication in Eaton's work which makes precise assessment difficult, most of the data have been collected based on the incidence of boron toxicity, and not the relative yield decline of the market product. Consequently, reliable, quantitative data to estimate yield reduction for most crops is still lacking. There is a need for further sand culture studies to be carried out using modern crop cultivars and with adequate treatments and replications to better pinpoint crop response to boron in soils. Ideally, data similar to that idealized in Figure 1 should result. Recently, Francois (1984) reported the effect of excess boron on tomato yields from large, outdoor sand culture studies. A linear regression analysis for relative yield showed that each unit increase in soil solution boron above the threshold value of 5.7 mg/L reduced tomato yield 3.4%.

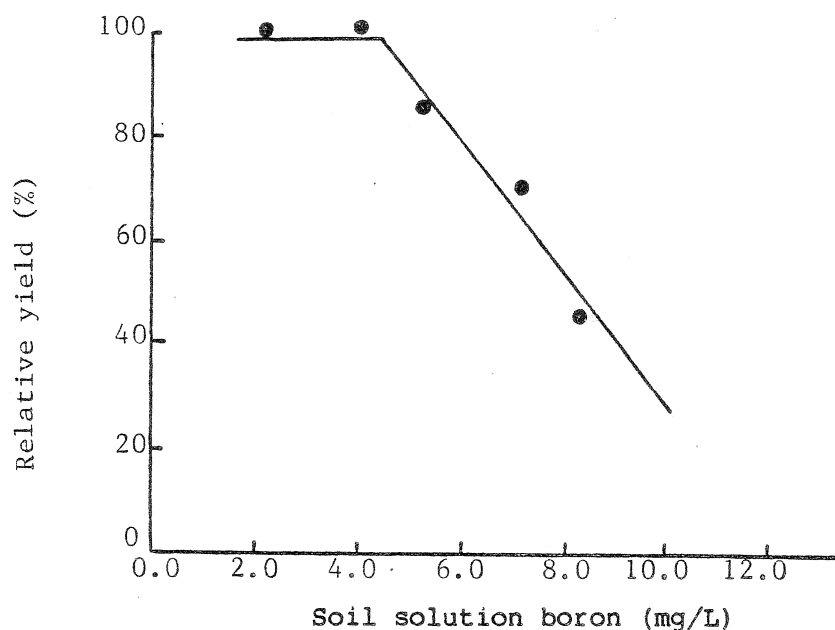


Fig. 1. Crop yield reduction as influenced by boron concentration of soil solution (Idealized)

CONCLUSIONS

- (1) Few irrigation waters have enough boron to injure plants directly. However, this source is one of the main causes of boron toxicity. The continued use and concentration of boron in the soil due to evapotranspiration is the reason for the eventual toxicity problems.
- (2) Current boron toxicity criteria used for evaluating irrigation water high in boron content are derived ultimately from Eaton's sand cul-

ture studies. However, two problems were noted when Eaton's data were being used. First, there is some confusion with regard to the "boron concentration" being cited in the literature. Some workers report the boron concentration as that of the irrigation water itself, others interpret it as the boron concentration of the soil saturation extracts. But we believe that in transposing Eaton's sand culture boron concentration to field conditions, we cannot use those values to represent boron concentration in irrigation water, but rather, should interpret them as boron concentration in the soil solution. Secondly, because of a lack of replication in Eaton's work, precision could not be assessed properly. Consequently, scientists have recommended differing criteria for irrigation water. Research to establish criteria for evaluating high boron levels in irrigation water is urgently needed.

- (3) Even though boron deficiency and toxicity of many crops has been appraised and reported extensively in the literature, it appears that some confusion still exists with regard to defining boron limits in soil for plant growth. In most cases the results presented are very site specific and the parameters (i.e., HWSB and saturation extract boron) used are not easily translated into the most important parameter, that is, the boron concentration in the soil solution.
- (4) At present the criteria that can be universally applied in determining any boron deficiency or toxicity for plants are those obtained from sand culture studies. This is because boron concentrations obtained in the latter can be easily related to soil solution concentrations; further, in such studies all roots are exposed to the same level of boron concentration, hence unambiguous conclusions can be drawn. However, in applying results obtained from sand culture to field conditions, adjustments must be made by considering boron distribution in soil, boron adsorption/desorption characteristics of the soil, the plant water uptake pattern, and environmental effects on boron uptake by plants.
- (5) In the past, a wide variety of crops have been examined for their boron requirement and tolerance to boron. Unfortunately, most of these data have been based on the incidence of boron deficiency or toxicity, and not on the relative yield decline of the market product. Some results obtained were derived from a very small plant population. Consequently, reliable quantitative data to estimate yield reduction for many crops is still lacking. There needs to be further sand culture type studies done using current crop cultivars and with adequate treatment and replication to better define crop response to boron.

RECOMMENDATIONS OF BORON CONTENT IN IRRIGATION WATER

Based on the literature review, we recommended to restrict the maximum concentration of 1.0 mg/L of boron for use on semitolerant crops in

long-term irrigated land. Recommended maximum concentration for tolerant plants is considered to be 3 mg/L of boron for normal irrigation practices. The criteria may be too conservative, however, caution is advisable in determining acceptable boron content in irrigation water until appropriate research information is developed.

Crop species differ widely in tolerance to boron. Alfalfa is benefited by boron concentrations high enough to injure cereal crops. Thus, an important consideration must be given to the problems that may arise if a farmer plans to change from a very boron-tolerant crop to a less tolerant crop if economic conditions change. When boron concentrations in soil solution are high enough to cause toxicity, the capacity of the adsorbed pool is usually high. Thus, the soil must be reclaimable.

The currently recommended method of reclaiming or detoxifying soils containing toxic levels of boron is to leach extensively with water (Prather 1977) or with other salt solutions (Il'in and Anikina 1974). Eaton and Wilcox (1939) found that boron fixed by soil could be desorbed and recovered by leaching with water. However, using water of low mineral content to leach boron is a slow process. Rhoades et al. (1970a) have stressed that soils whose soluble boron contents have been lowered to acceptable levels by leaching may in time regenerate soluble boron to toxic levels through desorption of the more strongly sorbed boron; this can only be prevented by continued leaching. Due to the adsorption/desorption characteristics of boron in soils, it would be expected that the rate of removal of boron by leaching will be much slower for boron than for other nonadsorbed salts. Reeve et al. (1955) found that while 30 cm of water per 30-cm depth of soil reduced soil salinity by 80% of its original level, it required 90 cm of water per 30 cm of soil to reduce boron to the same proportion. Bingham et al. (1972) also agreed that boron removal by leaching required about three times more water than the removal of the total salt content. Their data indicate a need for 3 to 3.7 m of water for leaching excessive boron (average concentration of 6.0 mg B/L in saturation extract) beyond the 1.5 m soil depth to a safe level of approximately 0.5-0.6 mg B/L in a loam to clay loam soil.

Thus, before establishing permissible boron limits in irrigation waters the long-term management plan of the irrigated land needs to be taken into consideration.

REFERENCES

- ALLISON, L.E. 1964. Boron. In A.G. Norman (Ed.), *Advances in Agronomy* 16: 139-180.
- AYERS, R.S. and Westcot, D.W. 1976. Water quality for irrigation. Irrigation and drainage paper 29, Food and Agriculture Organization of the United Nations, Rome Italy.
- BERNSTEIN, L. 1974. Crop growth and salinity. In *Agronomy* 17, Drainage for Agriculture, pp. 39-54, Amer. Soc. Agron., Madison, Wis.

- BINGHAM, F.T. 1973. Boron in cultivated soils and irrigation waters. p. 130-138. In E.L. Kothny, Ed. Trace Elements in the Environment. Adv. in Chem. Series 123, Am. Chem. Soc., Washington, D.C.
- BINGHAM, F.T. and GARBER, M.j. 1970. Zonal salinization of the root system with NaCl and boron in relation to growth and water uptake of corn plants. Soil Sci. Soc. Am. Proc. 34: 122-126.
- BINGHAM, F.T., MARSH, A.W., BRANSON, R., MAHLER, R. and FERRY, G. 1972. Reclamation of salt-affected high B soils in Western Karn County. Hilgardia 41: 195-211.
- EATON, F.M. 1935. Boron in soils and irrigation waters and its effect on plants. With particular reference to the San Joaquin Valley of California. U.S.D.A. Tech. Bull. No. 448. 131 pp.
- EATON, F.M. 1944. Deficiency, toxicity, and accumulation of boron in plants. J. Agric. Res. 69: 237-277.
- EATON, F.M. and WILCOX, L.V. 1939. The behaviour of boron in soils. U.S.D.A. Tech. Bull. No. 696. 57 pp.
- HATCHER, J.T., BLAIR, G.Y. and BOWER, C.A. 1959. Response of beans to dissolved and adsorbed boron. Soil Sci. 88: 98-100.
- IL'IN, V.B. and ANIKINA, A.P. 1974. Soil melioration: Boron salinization of soils. Soviet Soil Sci. 6: 68-75.
- INTERNATIONAL POPLAR RIVER WATER QUALITY BOARD OF THE INTERNATIONAL JOINT COMMISSION. 1979. International Poplar River Water Quality Study: Main Report. Ottawa, Ont. pp. 31-33.
- JAME, Y.W., NICHOLAICHUK, W., LEYSHON, A.J. and CAMPBELL, C.A. 1982. Boron concentration in the soil solution under irrigation: A theoretical analysis. Can. J. Soil Sci. 62: 461-470.
- NICHOLAICHUK, W., LEYSHON, A.J., JAME, Y.W. and CAMPBELL, C.W. 1983. Boron and salinity survey of irrigation projects in Saskatchewan. Proc. of the 1983 Soils and Crops Workshop, University of Saskatchewan, Saskatoon. pp. 242-256.
- PRATHER, R.J. 1977. Sulfuric acids as an amendment for reclaiming soils high in B. Soil Sci. Soc. Am. Proc. 41: 1098-1101.
- REEVE, O.C., PILLSBURY, A.F. and WILCOX, L.F. 1955. Reclamation of a saline and high B soil in the Coachella Valley of California. Hilgardia 24: 69-81.
- RHOADES, J.D., INGVBON, R.D. and HATCHER, J.J. 1970a. Laboratory determination of leachable soil boron. Soil Sci. Soc. Am. Proc. 34: 871-875.

- RYAN, J., MIYAMOTO, S. and STROEHLEIN, J.L. 1977. Relation of solute and sorbed boron to the boron hazard in irrigation water. Plant Soil 47: 253-256.
- SCOFIELD, C.S. 1936. The salinity of irrigation water. Smithsonian Report for 1935: 275-287.
- SHAINBERG, I. and OSTER, J.D. 1979. Quality of irrigation water. International Irrigation Information Center, Publ. 2. 65 pp.
- U.S. SALINITY LABORATORY STAFF. 1954. Diagnosis and improvement of saline and alkali soils. U.S. Dept. of Agric. Handbook No. 60, Washington, D.C.
- WILCOX, L.V. 1960. Boron injury to plants. U.S.D.A., A.R.S. Agric. Info. Bull. No. 211, pp. 3-7.